Army Research Laboratory

Calculating Low-Atmosphere Profile and Turbulence Information from Meteorological Sensors fitted to Battlefield Robotics Systems

Arnold Tunick, Stuart Young, and Robert Winkler

ARL-MR-523

20020606 069

Army Research Laboratory

Adelphi, MD 20783-1197

ARL-MR-523

Calculating Low-Atmosphere Profile and Turbulence Information from Meteorological Sensors fitted to Battlefield Robotics Systems

Arnold Tunick, Stuart Young, and Robert Winkler
Computational and Information Sciences Directorate

AQU02-09-1665

Abstract

This report describes a new data analysis and interpretation algorithm developed for a precision meteorological sensor that has been fitted to one of the Army Research Laboratory's (ARL) prototype robotics vehicles. The new algorithm provides low-atmosphere profile and turbulence information from the retrieval and analysis of wind speeds, wind directions, air pressure, and temperatures (1 Hz data). The algorithm is at first formulated for data collected over flat terrain at some low reference height above ground. We calculate the small interval (≤ 4.5 minute) averages and standard deviations for the wind and temperature fields and apply a simple log-law model to extrapolate wind velocity profile information upward through the sensor. Thus we initiate a coupling of meteorology to robotics for future military applications.

Contents

Figures

1. Introduction

The U.S. Army Research Laboratory (ARL) is developing several prototype robotics systems designed to carry combat sensors like infrared, video, and acoustic arrays. In addition, an all-terrain robotics vehicle is being fitted with a precision meteorological sensor to retrieve and construct local wind field, temperature, and turbulence information. It is expected that instantaneous meteorological measurements (with the use of atmospheric computer models) will provide important information to the Army's soldiers on the performance of future battlefield systems and communications (e.g., http://www.darpa.mil/fcs/index.html, 03-26-02).

Calculating low-atmosphere profile and turbulence information from robotics systems logically extends this new capability and provides a basis for adding additional sensors on future testbed vehicles. Therefore, we report here on a small electronic meteorological sensor, which will retrieve data at some low reference height above (at first) flat terrain. In addition we develop an analysis algorithm to calculate the small interval (≤ 4.5 min) averages and standard deviations for the wind and temperature fields. We then apply a simple log-law model to extrapolate profile information (~ 15 m) upward through the sensor. Improved or more sophisticated models for the lower boundary layer can be implemented later on for more complex areas, all while trying to determine the best configurations for single and multiple robotic vehicles (R. Meyers, 2001 personal communication). At that time, such algorithms will affect state-of-the-art theory and analysis, to include corrections for inhomogeneous and anisotropic turbulence conditions.

2. Electronic wind velocity and meteorological sensor

ARL's Robotics Systems Integration Team is investigating robotics designs, which include the implementation of data display and sensor systems as part of the Army's command and control architecture. Compact packaging is important. Therefore, one of the components being evaluated for an all-terrain robotics systems platform is the Cossonay[1] Model 500-C-M precision thermal anemometer and meteorological sensor. The Model 500-C-M sensor is compact, automatic, and self-contained with no moving parts (fig. 1). The Model 500-C-M is a patented, solid-state instrument that provides continuous digital (RS232) signal output and operates from a 12v DC power supply. The meteorological components, microprocessor, and electronics are enclosed in a sealed weatherproof casing. The sensor height, head width, body diameter, and total weight are 255 mm, 90 mm and 70 mm, and 1.5 kg, respectively. The Cossonay 500-C-M sensor measures wind speeds from 0 to 40 m/s (threshold 0.3 m/s), wind direction over 360°, air temperature from –40 to +60 °C (resolution 0.1 °C), and air pressure from 600 to 1200 mbar.

Figure 1. Front view of the Cossonay 500-C-M digital thermal anemometer and meteorological sensor. The sensor shown here has 3 platinum hot films mounted on a small ceramic tube installed vertically on the instrument head and is surrounded by a protective wire cage.
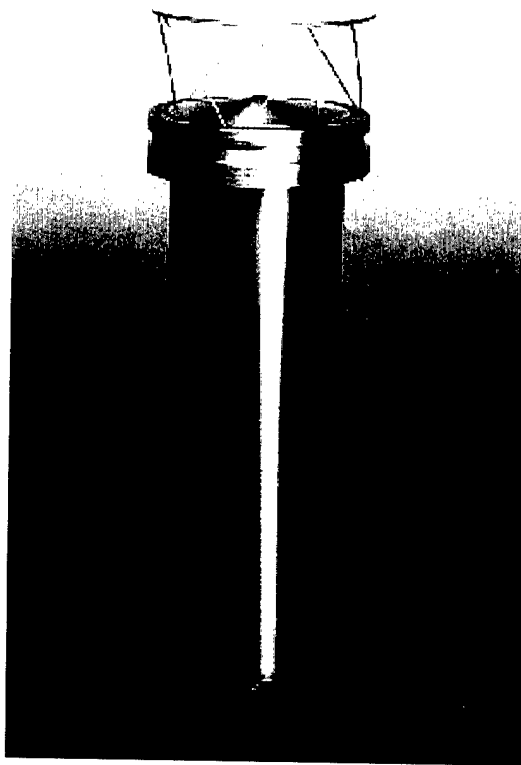
[1] The use of commercial or company names with regard to electronic products does not constitute an endorsement by the U.S. Army.

2

In general, thermal (or hot-film) anemometry is based on the microanalysis of convection currents as they are affected by wind flow across heated platinum wires encased by very thin (millimeter) glass films (e.g., Thompson and Hassman, 2001). The Model 500-C-M sensor shown here has 3 platinum hot films mounted on a small ceramic tube installed vertically on the instrument head and is surrounded by a protective wire cage. The hot film elements are maintained at a high constant temperature above ambient[2]. The sensor operates then as explained above, i.e., heat transferred to the atmosphere by convection will be greater for the hot film element, which is at the leading edge of the flow, than for the element, which is at the trailing edge. Therefore, the differences in temperature across the sensor elements are affected by the magnitude and direction of the wind and the temperature difference between the sensor elements and ambient air temperature. (Note: Ambient air temperature is detected by a standard platinum resistance thermometer, colocated on the instrument head, as shown in figure 1.)

In addition, the Model 500-C-M sensor houses a precision, micro-mechanical pressure sensor that features similar technology to that found in automobiles which trigger protective airbags upon impact. However, with regard to vibration or shock to the instrument package in mobile applications, it was suggested that future sensor designs may include a reinforced metal instrument basket, like that found on the Cossonay Series 270 sensors. Cossonay Series 270 crosswind sensors have been installed on tanks and other military ground vehicles (R. Jones, Personnal, Communication). Finally, the Model 500-C-M sensor will maintain accuracy with tilt up to 20° from vertical (Model 500 Operating Manual, 2001).

---

[2] Ducharme et al. (1994) reported on a Thermo Systems Inc.[1], Teflon coated hot-film sensor that operated at 250° C above ambient air temperature. In contrast, Thompson and Hassman (2001) report on a newer Sutron Instruments Co.[1] twin-hot-film sensor that operates at 100° C above ambient air temperature. The Cossonay 500-C-M sensor operates in the range 100–150° C.

3. Data analysis algorithm

In this section we present a simple data analysis algorithm for calculating the small interval (≤ 4.5 min) averages and standard deviations from measured wind speeds, wind directions, air pressure, and temperatures. We follow the example shown by an earlier program code for partitioning the raw data and filtering spurious noise (Chintawongvanich, 1993). This element of the calculation operates on the data in the following manner. We designate the number of points (e.g., ≤ 90) for the "small" averaging period, not to exceed 1.5 minutes of data retrieved at 1 Hz. Then we determine the width of the "large" averaging period, which will consist of some number (e.g., 2 or 3) of "small" averaging periods. In total, a "large" averaging period will contain ≤ 4.5 minutes of filtered data. Then we apply a noise-rejection (i.e., spike filtering) algorithm, which has the following properties. Once the "small" averaging period mean ($\overline{T}$) and fluctuation (T') values for each meteorological parameter are determined, then spurious noise is defined as individual data points having values greater than or equal in magnitude

to 3 standard deviations, e.g., $3\sigma_T$, where $\sigma_T = \sqrt{\dfrac{\sum\limits_{i=1}^{n}\left(T_i - \overline{T}\right)^2}{n-1}}$ (Quality Control Software, 2001). Here we consider the parameter air temperature (T_i),

where $\overline{T} = \frac{1}{n}\sum\limits_{i=1}^{n} T_i$ and $T' = T_i - \overline{T}$, where n is the number of data points. As a result, if data spikes are detected, the values of those data points are set to the mean for that averaging period.

The next element of the algorithm is the application of a simple log-law model to determine low-atmosphere wind velocity profile and turbulence information. As described by Munn (1966), the vertical wind profile in the absence of buoyancy (i.e., in adiabatic conditions) can be expressed as,

$$\overline{u}(z) = \frac{u_*}{k}\, \ln\left(\frac{z+z_0}{z_0}\right) \quad , \tag{1}$$

where

$\overline{u}$ is the mean wind (in units m/s),

$u_* = \sqrt{v\dfrac{\partial \overline{u}}{\partial z}}$ is the friction velocity (related to surface shearing stress),

v is kinematic viscosity (in units $m^2\!\big/s$),

z is height above ground level,

and

z_0 is the roughness (length) of the surface boundary.

Surface (aerodynamic) roughness of the landscape affects airflow close to the ground. The surface roughness length is a quantity that varies in the following manner: z_0 is ~10^{-4} m over snow, sand, dry lakebeds, or concrete, ~10^{-2}m over soils, and ~0.1 m over farmlands, tall grass, or shrubs (e.g., Oke, 1978; Pielke, 1984). Typical values for these data also can be found in a table compiled by Rachele and Tunick (1994). Knowing z and z_0, and having determined from the sensor retrieved data (as explained above), we can estimate a value for u_*, the friction velocity. Then the application of Eq. (1) allows us to extrapolate wind velocity profiles (~15 m) upward through the sensor (fig. 2). In addition, we have calculated a useful turbulence parameter, the square of which (in simplified form) can be equated to the surface momentum flux, i.e., $u_*^2 = -\overline{u'w'}$ is the rate that momentum is transferred downward due to surface friction. Likewise, the square of the friction velocity provides an estimate of the surface shearing stress (per unit mass per unit volume of air), i.e., the drag force. This parameter is an important element in determining the surface layer budget of turbulent kinetic energy.

Alternately we can estimate surface layer wind velocity profiles using a power-law exponent model, such as described by Touma (1977) and Irwin (1979), i.e.

$$\overline{u}(z) = \overline{u}_r\left(\frac{z}{z_r}\right)^p \quad , \tag{2}$$

where $\overline{u}_r$ is the mean wind velocity at reference height, z_r, and p is specified as a function of static (thermal) stability and surface roughness. These authors have provided tables to give examples of predicted and observed values for the power-law exponent, p, for various sites.

Figure 2. Schematic showing wind velocity profile information provided through application of a simple log-law model.
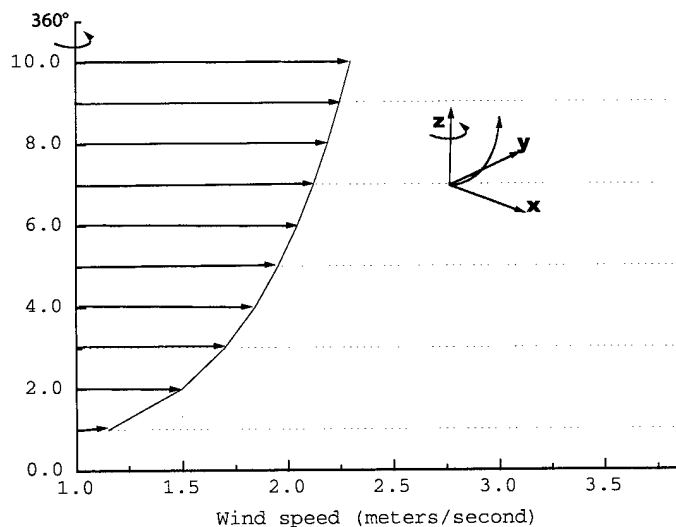
For now, we present the simple log-law and power-law formulations described above to extrapolate wind profile information upward through the sensor. In future algorithms we will improve upon these using more sophisticated wind profile models for the lower-boundary layer for day and nighttime conditions, such as those described by Santoso and Stull (1998, 2001).

To complete the algorithm, we the calculate the surface layer vertical temperature profile as described by Hess (1979), i.e.,

$$\overline{T}(z) = \overline{T}_r + \Gamma(z - z_r) ,\qquad (3)$$

where $\overline{T}(z)$ is the mean temperature profile, $\overline{T}_r$ is temperature at the reference height, and Γ is the adiabatic lapse rate, i.e., $\Gamma = -0.0098\ °C/m$. In the absence of buoyancy, i.e., neutral (windy) conditions, temperatures in the surface layer often vary linearly with height.

4. Summary and Conclusions

A precision thermal anemometer and meteorological sensor is being evaluated for implementation onto one of ARL's all-terrain, prototype, robotics vehicles. Compact packing is important, so that in application, this meteorological sensor system can be used to retrieve and construct local wind field, temperature, and turbulence information alongside infrared, video, and acoustic arrays. It is expected that instantaneous meteorological measurements (with the use of atmospheric computer models) will contribute useful information on the performance of future battle field sensors and communications and thus affect elements of the Army's command and control architectures.

In this report, therefore we presented a new algorithm to calculate micrometeorological profile and turbulence information, which includes a simple data analysis algorithm for calculating the small interval (≤ 4.5 min) averages and standard deviations from measured data. In addition, we described an algorithm that extrapolates wind field and temperature profile information upward through the sensors platform and provided estimates of an important turbulence parameter related to surface wind shear. As a result, we have intiated a coupling of meterology to robotics for future military sensor and systems applications.

7

Acknowledgements

8

References

1. Chintawongvanich, P., 1993: *Program SONIC (a FORTRAN code)*. Physical Sciences Laboratory, New Mexico State University.

2. Ducharme, K.M., D.R. Miller, and D.E. Aylor, 1994: The feasibility of using a hot-film anemometer in the rain. *J. Atmos. Oceanic Technol.*, **11**, 1415-1419.

3. Hess, S.L., 1979: *Introduction to Theoretical Meteorology*. Robert E. Krieger Publishing Co., Huntington, NY, 362 pp.

4. Irwin, J.S., 1979: A theoretical variation of the wind profile power-law exponent as a function of surface roughness and stability. *Atmos. Environ.*, **13**, 191-194.

5. Munn, R.E., 1966: *Descriptive Micrometeorology*. Academic Press, New York, 245 p.

6. Oke, T. R., 1978: *Boundary Layer Climates*, Methuen, London, 372 p.

7. Pielke, R. A., 1984: *Mesoscale Meteorological Modeling*, Academic Press, New York, 612 p..

8. Quality Control Software: Version 2.1, 2001: Boundary Layer Group, College of Oceanic and Atmospheric Sciences Oregon State University, http://blg.oce.orst.edu/Software/QC_v2/.

9. Rachele, H. and A. Tunick, 1994: Energy balance model for imagery and electromagnetic propagation, *J. Appl. Meteor.*, **33**, pp. 964-976.

10. Santoso, E. and R. Stull, 1998: Wind and temperature profiles in the Radix layer: The bottom fifth of the convective boundary layer. *J. Atmos. Sci.*, **37**, 545-558.

11. Santoso, E. and R. Stull, 2001: Similarity equations for wind and temperature profiles in the Radix layer, at the bottom of the convective boundary layer. *J. Atmos. Sci.*, **58**, 1446-1464.

12. Thompson, B.E., and R.C. Hassman, Jr., 2001: Meteorological twin-hot-film-amemometry. *J. Atmos. Oceanic Technol.*, **18**, 493-502.

13. Touma, J.S., 1977: Dependence of the wind profile power law on stability for various locations. *J. Air Pollut. Control Assoc.*, **27**, 863-866.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED Final, 7/01–11/01

4. TITLE AND SUBTITLE Calculating Low-Atmosphere Profile and Turbulence Information from Meteorological Sensors fitted to Battlefield Robotics Systems

5. FUNDING NUMBERS

DA PR: AH16
PE: 62120A

6. AUTHOR(S) Arnold Tunick, Stuart Young, and Robert Winkler

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
Attn: AMSRL- CI-EP   email: atunick@arl.army.mil
2800 Powder Mill Road
Adelphi, MD 20783-1197

8. PERFORMING ORGANIZATION REPORT NUMBER
ARL-MR-523

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
2800 Powder Mill Road
Adelphi, MD 20783-1197

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
ARL PR: 2FE4H3
AMS code: 622120H1611

12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
This report describes a new data analysis and interpretation algorithm developed for a precision meteorological sensor that has been fitted to one of the Army Research Laboratory's (ARL) prototype robotics vehicles. The new algorithm provides low-atmosphere profile and turbulence information from the retrieval and analysis of wind speeds, wind directions, air pressure, and temperatures (1 Hz data). The algorithm is at first formulated for data collected over flat terrain at some low reference height above ground. We calculate the small interval ($\leq$ 4.5 minute) averages and standard deviations for the wind and temperature fields and apply a simple log-law model to extrapolate wind velocity profile information upward through the sensor. Thus we initiate a coupling of meteorology to robotics for future military applications.

14. SUBJECT TERMS Data analysis, computer model, wind velocity, thermal anemometer, micrometeorology, Future Combat Systems

15. NUMBER OF PAGES
14

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

11